NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3742

TENSILE PROPERTIES OF HK31XA-H24 MAGNESIUM-ALLOY SHEET UNDER RAPID-HEATING CONDITIONS AND CONSTANT ELEVATED TEMPERATURES

By Thomas W. Gibbs

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

Specimens of HK31XA-H24 magnesium-alloy sheet from an experimental batch were heated to failure at nominal temperature rates from 0.2° F to 100° F per second under constant-load conditions. Rapid-heating yield and rupture stresses are presented and compared with the yield and ultimate stresses from elevated-temperature tensile stress-strain tests for $\frac{1}{2}$-hour exposure. Linear temperature-rate parameters were used to correlate rapid-heating results by constructing master curves which can be used for predicting yield stresses and temperatures and for estimating rupture stresses and temperatures.

INTRODUCTION

A new temperature-resistant magnesium-thorium alloy, presently designated as HK31XA, has recently become available as a commercial sheet material. Considerable interest has been evidenced in HK31XA for aircraft and missile structural applications in the low elevated-temperature range. In a preliminary evaluation (ref. 1), this material was shown to have promising tensile and creep properties and good corrosion resistance.

In order to provide information on the tensile properties of HK31XA-H24 magnesium-alloy sheet under rapid-heating conditions, the material has been included in an experimental program (refs. 2 and 3) at the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics. In this program, materials under constant load are heated to failure at nominal temperature rates from 0.2° F to 100° F per second. Conventional short-time elevated-temperature tensile tests are also performed on the material to determine the elastic moduli and the yield and ultimate stresses for comparison with the rapid-heating results.

The results of the rapid-heating tests of HK31XA-H24 magnesium-alloy sheet are presented herein together with the results of conventional short-time elevated-temperature tensile tests. Typical strength properties of HK31XA-H24 have not been established because the sheet material is still in the experimental stage of development.

SPECIMENS

Test specimens, machined and supplied by The Dow Chemical Company, were cut from a single 0.064-inch-thick sheet of HK31XA-H24 magnesium-alloy with the longitudinal axis of the specimens taken parallel to the rolling direction. At this laboratory, a few additional specimens were machined from another 0.064-inch-thick HK31XA-H24 sheet for use in checking the consistency of tensile properties derived from separate batches of material. Specimens having the dimensions of the specimen shown in figure 1 were used for the conventional short-time elevated-temperature tensile tests as well as for the rapid-heating tests.

The nominal composition of HK31XA-H24 magnesium-alloy is 3.0 percent thorium, 0.7 percent zirconium, and the balance magnesium. An analysis of the sheet tested in the program was furnished by The Dow Chemical Company and showed 2.5 percent thorium, 0.6 percent zirconium, and the balance magnesium. The material was received in the H24 temper which was attained by rolling, followed by partial annealing at 625° F for one hour. The surface of the specimen was not coated or otherwise treated.

TEST PROCEDURE

Equipment and procedures used in performing conventional short-time elevated-temperature tensile tests on HK31XA-H24 were the same as those described in reference 4. During a test, the specimen was exposed to the test temperature for 1/2 hour before loading to failure at a constant strain rate of 0.002 per minute; however, a few tests were run at a rate of 0.008 per minute. The test temperature was controlled to an accuracy of ±10° F during the exposure period and ±5° F during the test. The stress-strain curve was recorded autographically and the strain rate was determined from a time-strain curve plotted simultaneously with the stress-strain curve. Both curves could be followed visually during a test. The yield stress was determined with an accuracy of ±2 percent and the ultimate stress, with an accuracy of ±1/2 percent.

Equipment and procedures used in performing rapid-heating tests were the same as those described in references 2 and 3. During a test, the specimen was loaded to the desired stress by a dead-weight loading system and heated to failure at a constant temperature rate by passing an electric current through the reduced section of the specimen. (See fig. 1.) Strains were measured with an accuracy of ±2 percent over a 1-inch gage length at the center of the reduced section of the specimen by two linear differential variable transformers connected to the specimen by lever arms and gage frames. For duplicate temperature records, two thermocouples were peened into the 1-inch gage length at symmetrical locations. Temperatures were measured with an accuracy of ±5° F.

RESULTS AND DISCUSSION

Stress-Strain Tests

The results of the elevated-temperature tensile stress-strain tests of HK31XA-H24 magnesium-alloy sheet are given in table 1 and figures 2 and 3. Tensile stress-strain curves for 80°, 300°, 400°, and 600° F are shown in figure 2. The 0.2-percent-offset yield stresses are denoted by tick marks. In table 1 and figure 2 the results show that yield and ultimate stresses obtained at a strain rate of 0.008 per minute are higher than corresponding properties obtained at a strain rate of 0.002 per minute.

The material in a few of the specimens supplied by The Dow Chemical Company did not seem to be completely homogeneous. One specimen developed a brittle fracture at room temperature when it was loaded to only a fraction of its normal strength. A brownish discoloration was noted in the fractured area. The discoloration was probably caused by an inclusion; however, a low-melting-point constituent oxidized in previous heat treatment could also have caused the discoloration. Results of tests at 80° F and 600° F performed on a few specimens machined at this laboratory from a second sheet of 0.064-inch-thick HK31XA-H24 were in excellent agreement with the results of the tests from specimens of The Dow Chemical Company reported herein.

The variation of Young's modulus with temperature is shown in figure 3. Considerable scatter is evident for the results at elevated temperatures. This scatter can be expected, however, in view of the rounded shape of the stress-strain curves (fig. 2) and the inaccuracy involved in determination of the slope of such curves over a small initial region.

The variation of the tensile yield and ultimate stresses with temperature is also shown in figure 3. These results are considerably lower over the entire temperature range than those reported in reference 1. At room temperature the yield and ultimate stresses reported herein are about 75 and 85 percent, respectively, of the values reported in reference 1 and at 600° F, about 37 and 30 percent, respectively.

The relatively low stresses reported herein can most likely be attributed to the slow strain rate of 0.002 per minute employed in the test. In a trial test at 600° F the strain rate was increased arbitrarily after necking occurred. In this case the ultimate stress was approximately 10 ksi or about $2\frac{1}{2}$ times that obtained in tests where the strain rate was maintained at 0.002 per minute. The value of 10 ksi is in close agreement with the results at 600° F reported in reference 1 and indicates that a strain rate considerably faster than 0.002 per minute was employed in the tests reported therein.

Rapid-Heating Tests

Results of the rapid-heating tests are given in table 2 and in figures 4 to 10. Average values of the coefficient of thermal expansion obtained from the rapid-heating tests at a stress of 0.4 ksi are given in table 3.

Strain-temperature histories.- The strain-temperature histories for individual rapid-heating tests at four stress levels are illustrated in figure 4 for temperature rates from 0.2° F to 150° F per second. The groups of curves are spaced for ease of reading. The strains are total strains which include elastic, thermal, and plastic strains. Yield temperatures, indicated by the tick marks, are defined as the temperatures at which 0.2-percent plastic flow occurs as a result of heating the specimen under load. The tick marks are offset 0.2 percent from a calculated reference curve denoted as the calculated curve in figure 4. The calculated curve is constructed by adding the elastic strain to the thermal-expansion strain. The elastic strains at the various temperatures are calculated from the corresponding elastic moduli at each stress level. At 15 and 20 ksi, however, initial plastic strains occurred on loading at room temperature; these plastic strains were determined from the stress-strain curve and were added to the elastic strains and thermal expansion at the various temperatures to construct the calculated curve for these stress levels.

At each stress level a regular family of curves is obtained. The rapid-heating curves coincide with the calculated curves until plastic flow occurs at elevated temperatures. The divergence of the test curve from the calculated curves is usually gradual until yield temperatures are reached.

Yield temperatures and stresses.- Yield temperatures obtained at the different stress levels are plotted in figure 5 against the temperature rate on semilogarithmic paper. In general, the increase of yield temperature with the logarithm of the temperature rate is approximately linear. Deviations from linearity are small in all cases.

Yield stresses, obtained under rapid-heating conditions, are compared in figure 6 with the tensile yield stresses from the stress-strain tests under constant-temperature conditions. The rapid-heating curves for nominal temperature rates from 0.2° F to 100° F per second were obtained from the experimental curves of figure 5. Above about 500° F there is a remarkable increase in yield stress for temperature rates of 60° F and 100° F per second as compared with the results of the conventional stress-strain tests for $\frac{1}{2}$- hour exposure. At 600° F, the yield stress for 100° F per second is about four times higher than the yield stress for the conventional elevated-temperature tensile tests.

A correlation of the results for yield stresses and temperatures from rapid-heating tests was effected by use of a linear temperature-rate parameter described in reference 2. The parameter was derived by extrapolating the linear experimental yield-temperature curves in figure 5 to the best common point. The coordinates of this point are the constants in the resulting parameter. The correlation in the form of a master curve is presented in figure 7 and appears to be very satisfactory. The parameter employed was

$$\frac{T + 70}{\log h + 8} \tag{1}$$

where T is the yield temperature in °F and h is the temperature rate in °F per second.

The accuracy with which yield temperatures can be predicted when the master curve (fig. 7) and the parameter (1) are used is shown in figure 5 by a comparison with the test results.

<u>Rupture temperatures and stresses</u>.- Rupture temperatures obtained at different stress levels are plotted in figure 8 against the temperature rate on semilogarithmic paper. Straight lines have been used to approximate the irregular pattern of the test points. The primary reasons for such irregularity were probably the effects of localized heating when necking occurred and the inconsistent behavior of the specimens at failure. Most often the specimens failed at a place other than that at which a thermocouple was located; then, a low value of the rupture temperature was recorded. Elongations were usually large but occasionally a brittle fracture occurred. Considering the above difficulties encountered in obtaining rupture data, the rupture data presented herein should be treated conservatively.

A comparison of rapid-heating rupture stresses with the conventional ultimate tensile stresses for $\frac{1}{2}$- hour exposure is given in figure 9 and shows that the former is nearly six times the latter at 600° F for a temperature rate of 100° F per second. The rapid-heating curves were prepared from the experimental curves of figure 8.

A correlation of rupture stresses and temperatures by use of a linear temperature-rate parameter is presented in the master curve of figure 10. The parameter employed was

$$\frac{T - 1060}{\log h - 7} \tag{2}$$

The correlation, however, is considerably worse than that for yield stresses and temperatures in figure 7. The poor correlation is emphasized by comparison of calculated and experimental rupture temperatures shown in figure 8. The master curve for rupture stresses and temperatures in figure 10 is probably of limited usefulness; however, it is presented for the purpose of estimating rupture temperatures.

CONCLUDING REMARKS

The rapid-heating tests of HK31XA-H24 magnesium-alloy sheet under constant load indicate that the yield and rupture temperatures vary approximately linearly with the logarithm of the nominal temperature rates from 0.2° F to 100° F per second.

Yield and rupture stresses obtained under rapid-heating conditions can either be less than or greater than the corresponding yield and ultimate stresses obtained in stress-strain tests. At the higher temperature rates of 60° F and 100° F per second, the yield and rupture stresses are of the order of four to six times greater than the results of the stress-strain tests at 600° F.

Temperature-rate parameters make possible the correlation and construction of master curves for stresses and temperatures of yield and rupture that take into account the effects of temperature rate. The correlation is very good for yield data but is relatively poor for rupture data.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 2, 1956.

REFERENCES

1. Johnson, H. A., ed.: Experimental Magnesium Alloys. Pt. 4 - Evaluation of HK31. WADC Tech. Rep. 54-83, Pt. 4 (Materials Lab. Contract No. AF(600)19147), Wright Air Dev. Center, U. S. Air Force, June 1954.

2. Heimerl, George J., and Inge, John E.: Tensile Properties of 7075-T6 and 2024-T3 Aluminum-Alloy Sheet Heated at Uniform Temperature Rates Under Constant Load. NACA TN 3462, 1955.

3. Heimerl, George J., Kurg, Ivo M., and Inge, John E.: Tensile Properties of Inconel and RS-120 Titanium-Alloy Sheet Under Rapid-Heating and Constant-Temperature Conditions. NACA TN 3731, 1956.

4. Hughes, Philip J., Inge, John E., and Prosser, Stanley B.: Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures. NACA TN 3315, 1954.

TABLE 1

TENSILE STRESS-STRAIN PROPERTIES OF 0.064-INCH-THICK

HK31XA-H24 MAGNESIUM-ALLOY SHEET

FOR $\frac{1}{2}$- HOUR EXPOSURE

Temperature, °F	Yield stress, ksi	Ultimate stress, ksi	Young's modulus, psi	Elongation in 2 inches, percent
Strain rate of 0.002 per minute				
80	25.0 25.0	31.9 30.7	6.10×10^6 6.10	-- --
300	18.4 19.2 17.5	20.3 20.5 19.5	5.80 6.15 5.40	32 25 21
400	15.6 15.8	16.8 16.8	5.56 6.00	24 23
600	3.1 3.0 3.0	3.2 3.1 3.4	3.79 3.52 4.10	65 18 43
Strain rate of 0.008 per minute				
400	16.2	17.1	6.00	60
600	3.4	4.8	3.70	49

TABLE 2

TENSILE PROPERTIES OF HK31XA-H24 MAGNESIUM-ALLOY

SHEET FOR TEMPERATURE RATES FROM

0.2° F TO 150° F PER SECOND

Stress, ksi	Temperature rate, °F/sec	Yield temperature, °F	Rupture temperature, °F	Elongation in 2 inches, percent
5	0.2	501	650	16
	2.0	563	---	26
	20.0	627	755	12
	60.0	666	780	17
	100.0	697	---	18
10	0.2	446	590	10
	.2	446	580	3
	2.0	501	595	3
	20.0	605	660	7
	20.0	605	700	13
	60.0	633	---	23
	100.0	650	---	16
15	2.0	400	508	10
	20.0	453	595	23
	60.0	477	668	20
	150.0	504	655	3
20	0.2	212	230	11
	2.0	248	375	8
	20.0	293	435	9
	60.0	307	513	11
	83.0	319	555	11

TABLE 3

AVERAGE VALUES OF COEFFICIENT OF THERMAL EXPANSION

FOR HK31XA-H24 MAGNESIUM ALLOY

Temperature range, °F	Average coefficient of expansion, per °F (a)
80 to 200	12.1×10^{-6}
80 to 300	13.4
80 to 400	14.0
80 to 500	14.5
80 to 600	15.0

[a]Values obtained from figure 3.

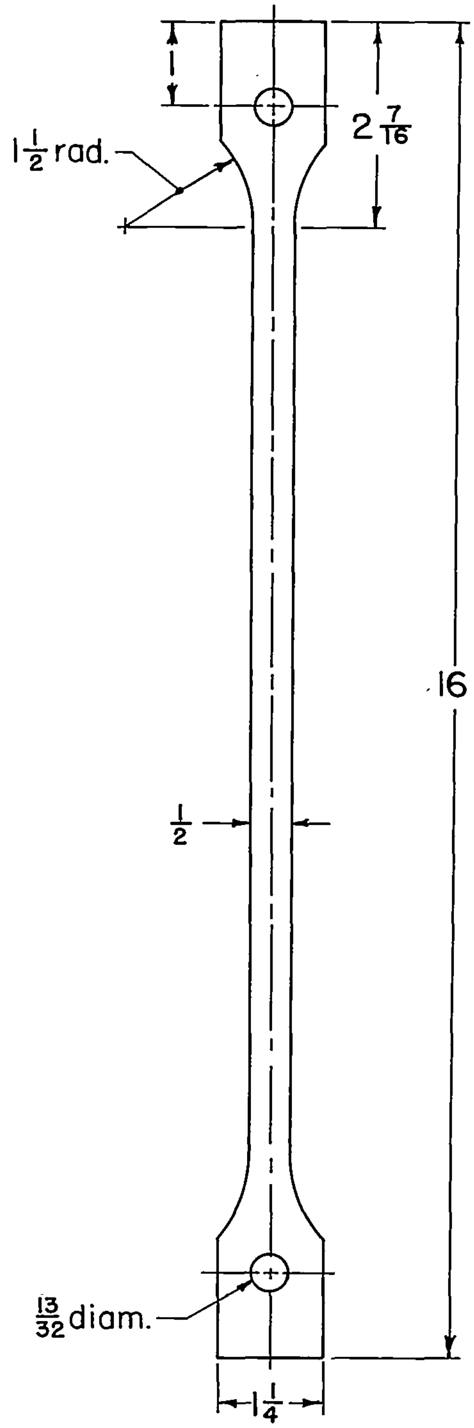

Figure 1.- Tensile specimen used for rapid-heating and stress-strain tests. All dimensions are in inches.

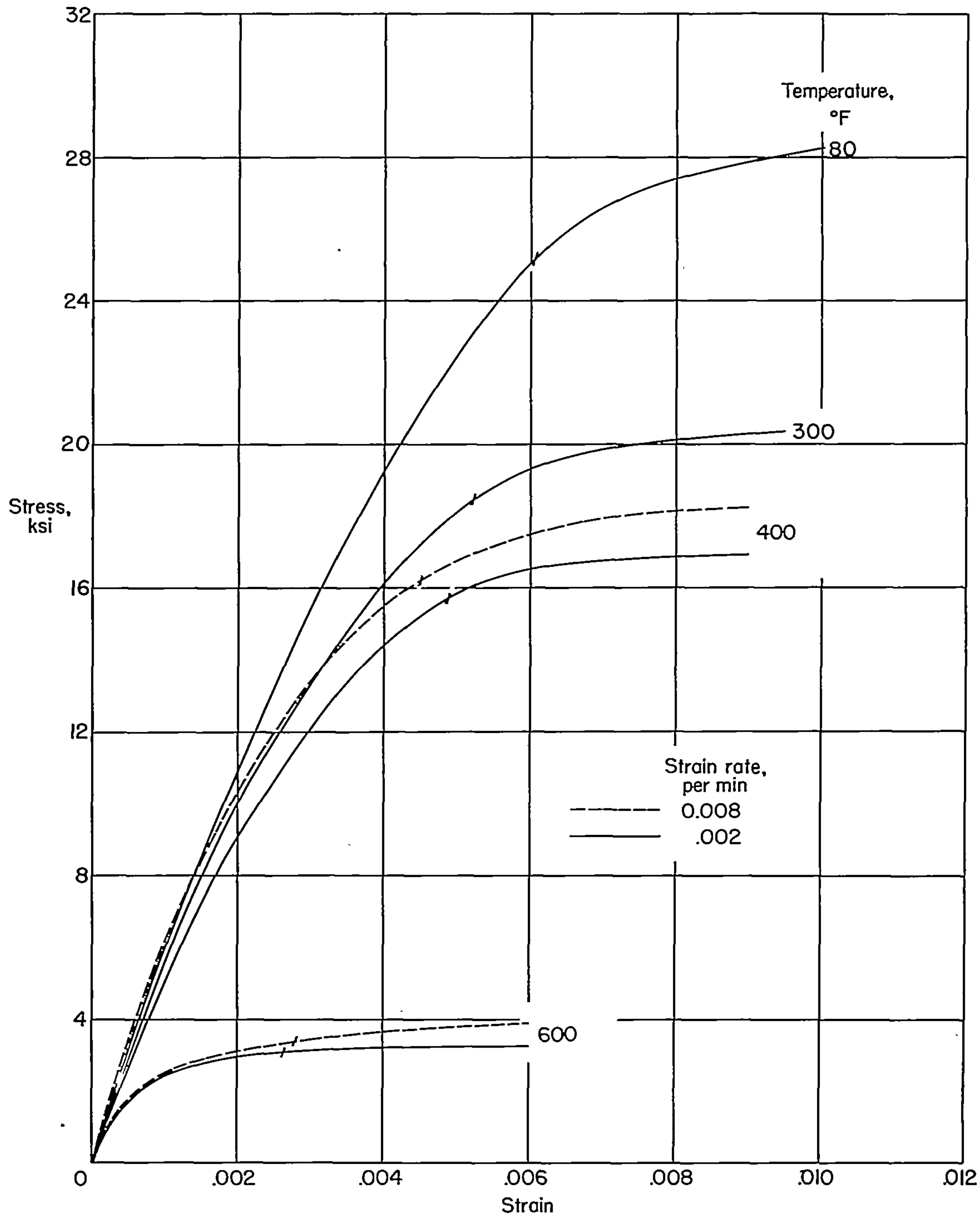

Figure 2.- Representative tensile stress-strain curves for HK31XA-H24 magnesium-alloy sheet at elevated temperatures for $\frac{1}{2}$-hour exposure.

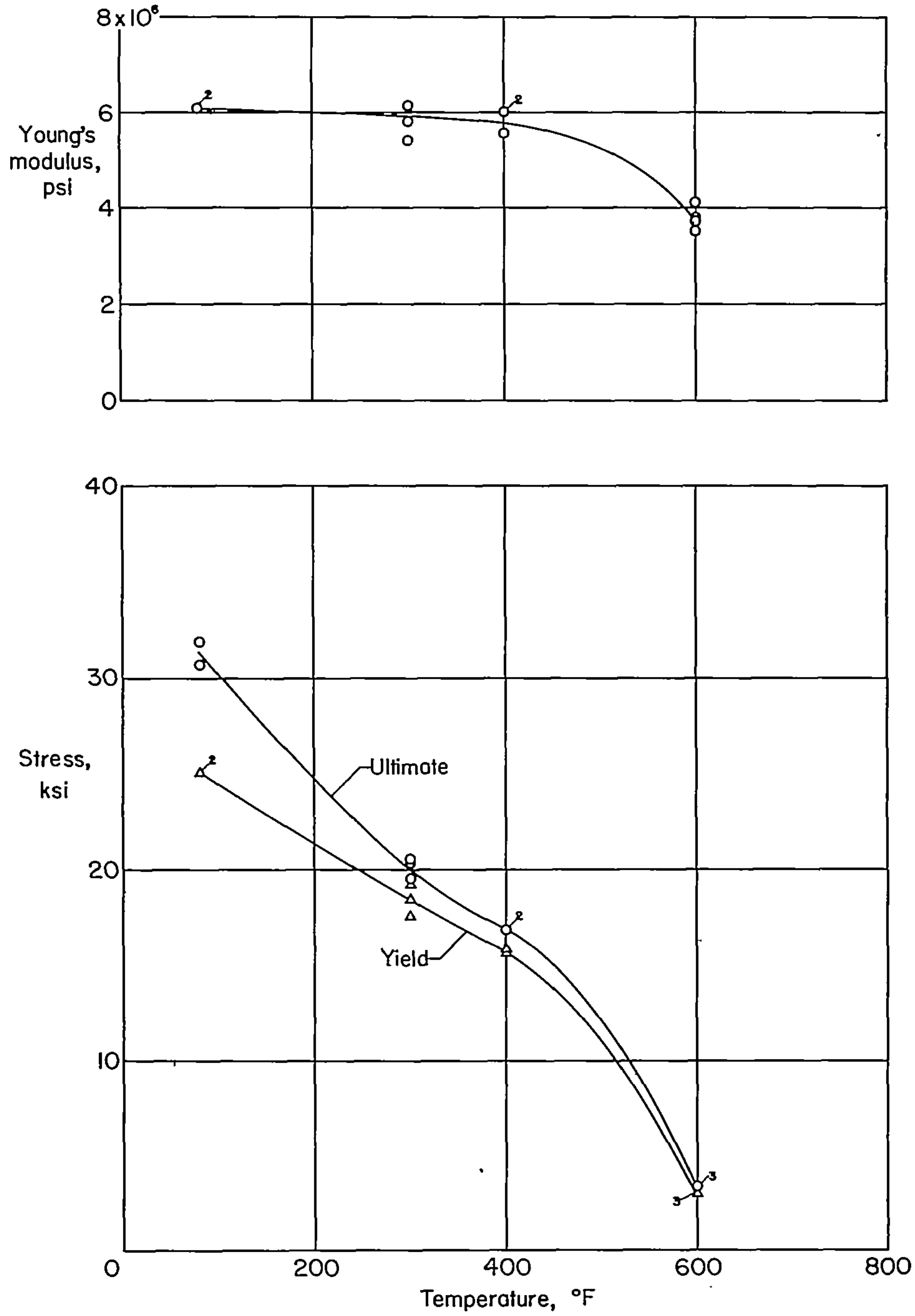

Figure 3.- Young's modulus, tensile yield stress, and ultimate stress for HK31XA-H24 magnesium-alloy sheet at elevated temperatures for $\frac{1}{2}$- hour exposure and at a strain rate of 0.002 per minute.

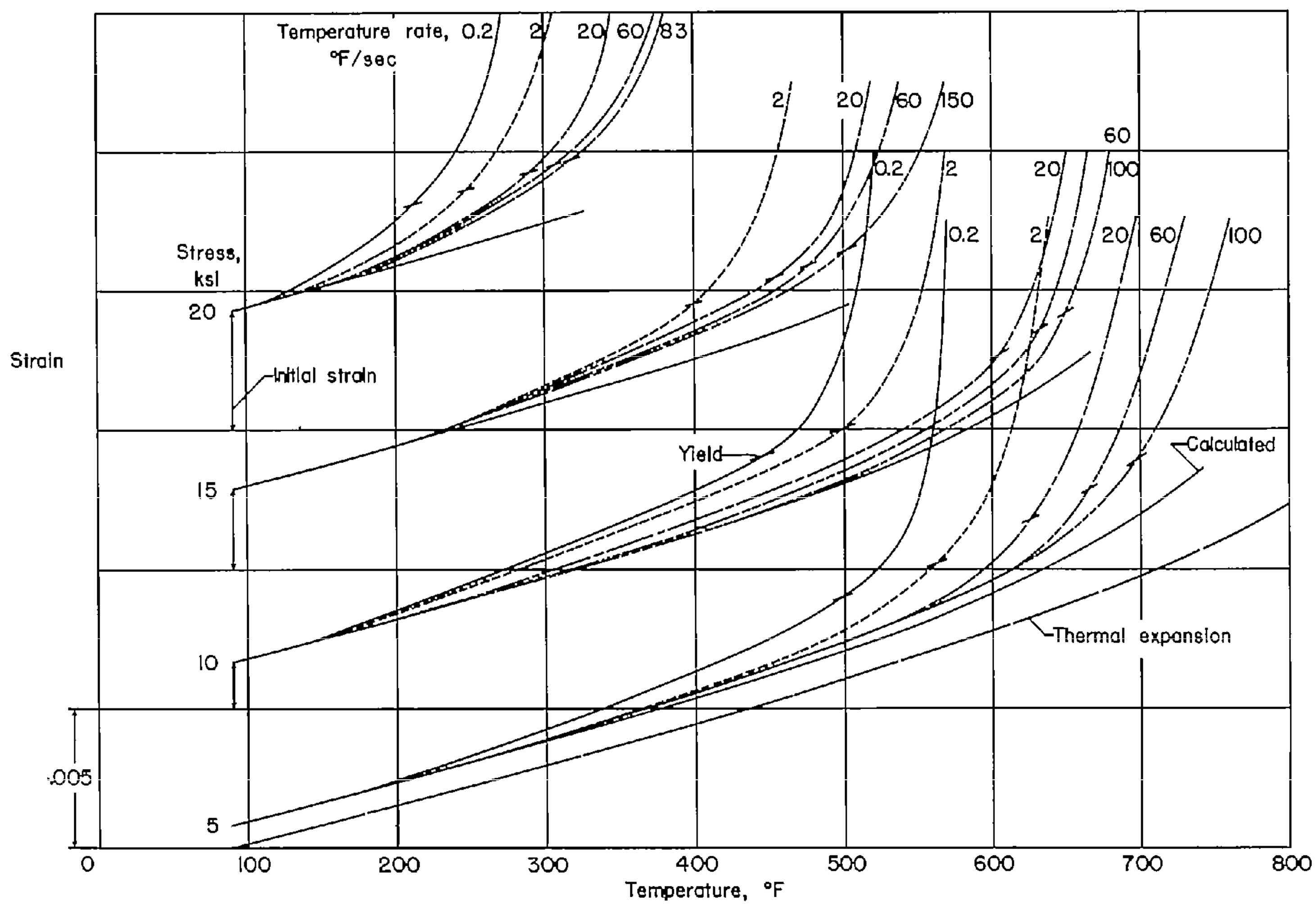

Figure 4.- Strain-temperature histories for HK31XA-H24 magnesium-alloy sheet at temperature rates from 0.2° F to 150° F per second at various stresses.

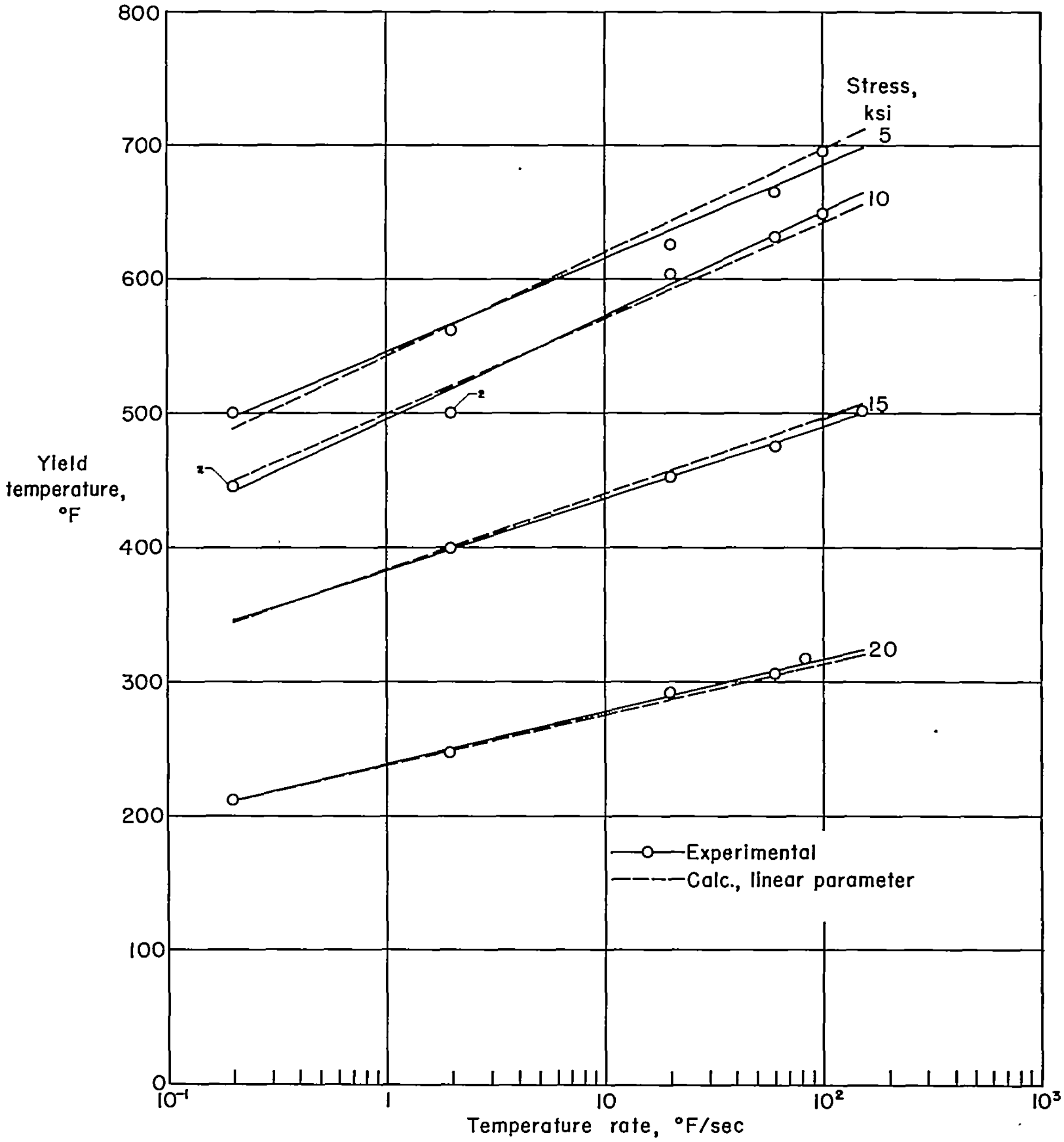

Figure 5.- Experimental and calculated yield temperatures for HK31XA-H24 magnesium-alloy sheet at temperature rates from 0.2° F to 150° F per second at various stresses.

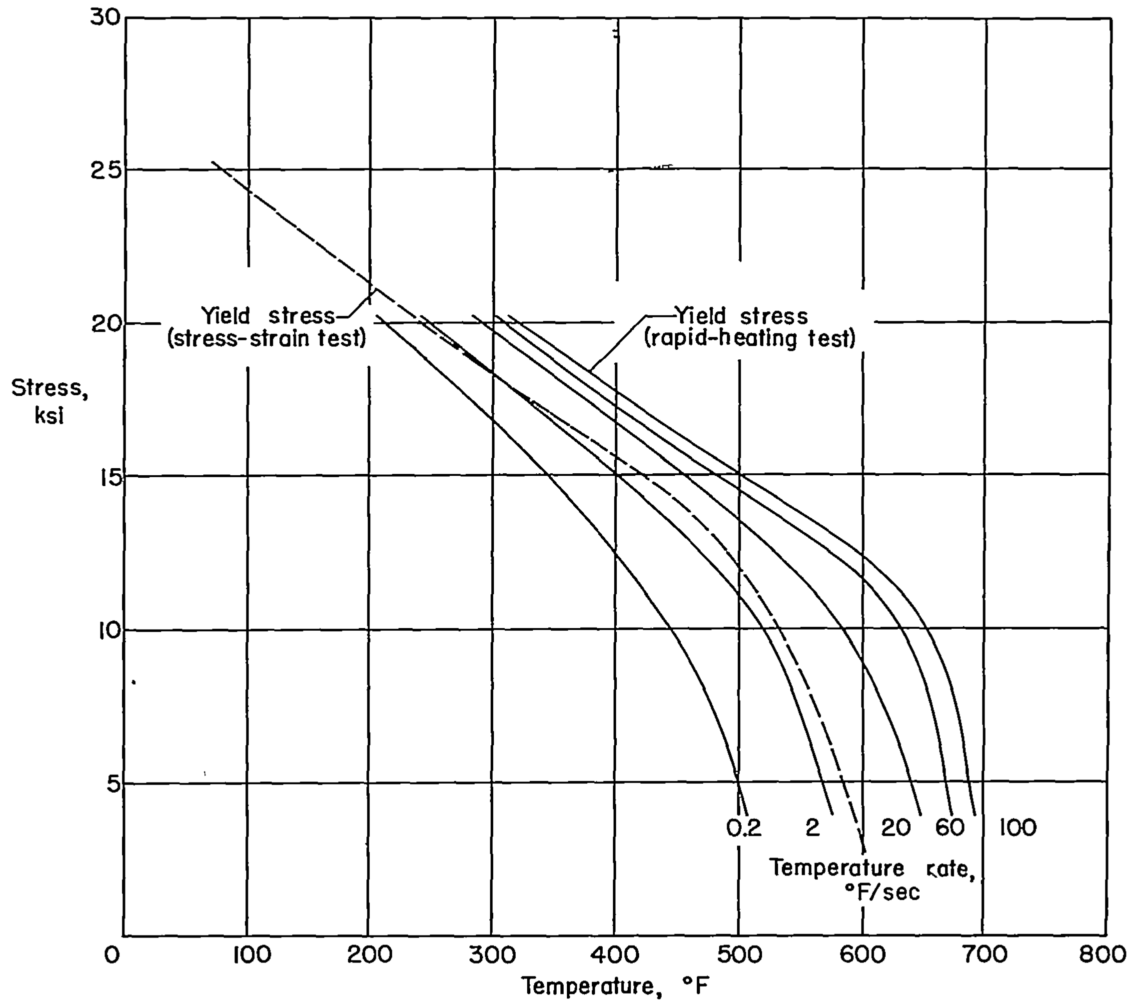

Figure 6.- Tensile yield stress of HK31XA-H24 magnesium-alloy sheet for rapid-heating tests from 0.2° F to 100° F per second and for stress-strain tests at elevated temperatures after $\frac{1}{2}$-hour exposure.

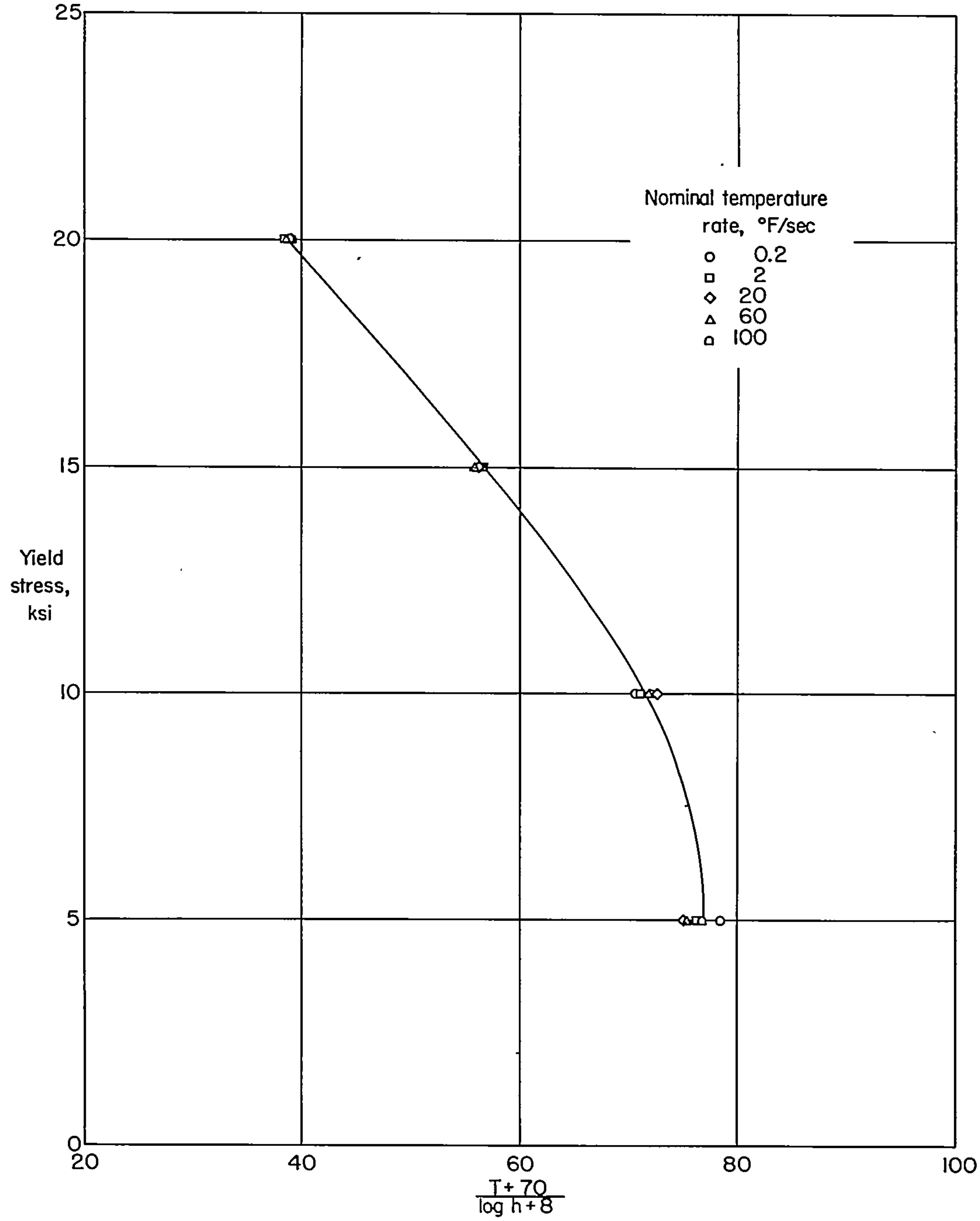

Figure 7.- Master curve for yield temperatures and stresses of HK31XA-H24 magnesium alloy, using the temperature-rate parameter $\frac{T + 70}{\log h + 8}$ (T is in $^{\circ}$F and h is in $^{\circ}$F per second).

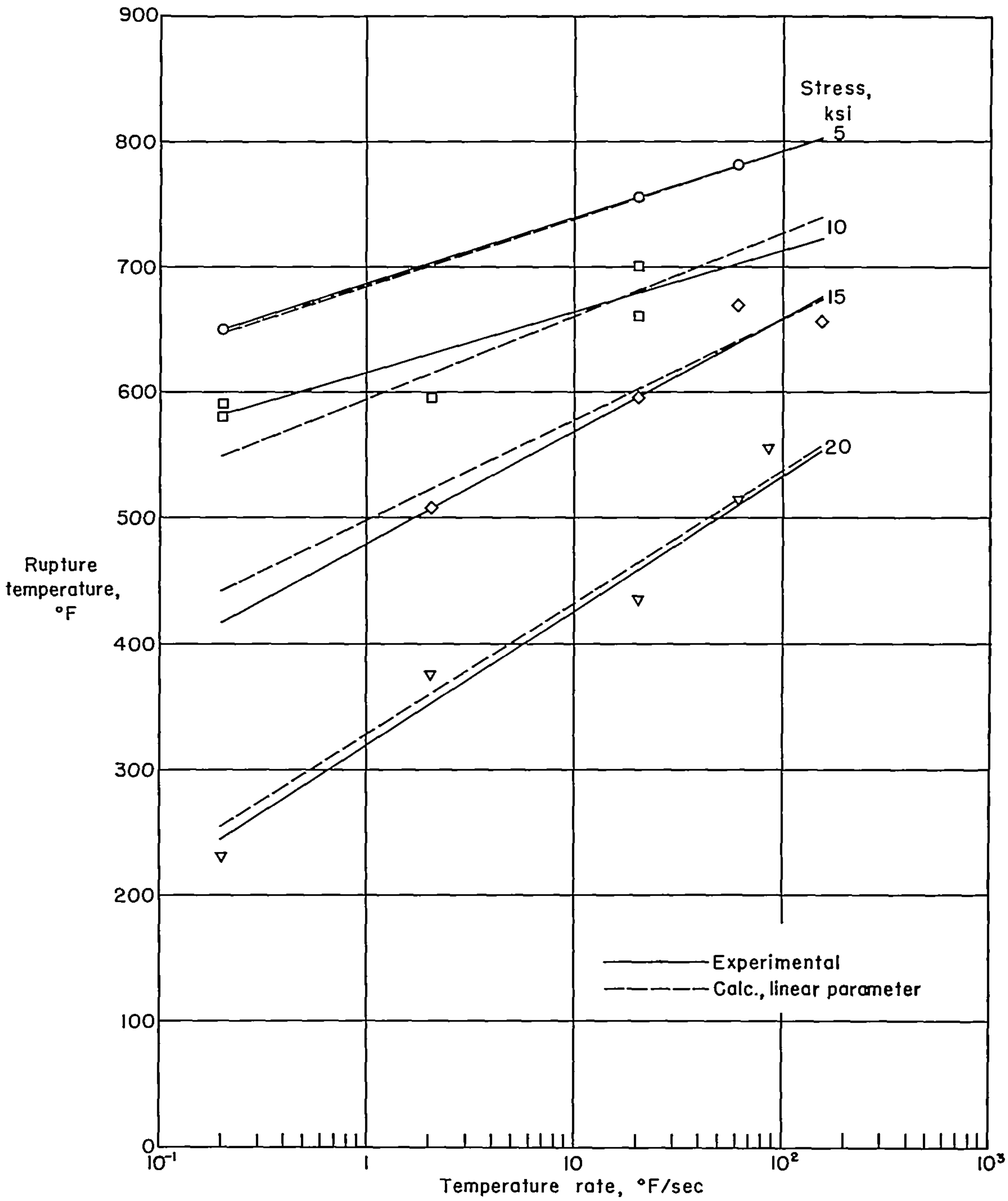

Figure 8.- Experimental and calculated rupture temperatures for HK31XA-H24 magnesium-alloy sheet at temperature rates from 0.2° F to 150° F per second at various stresses.

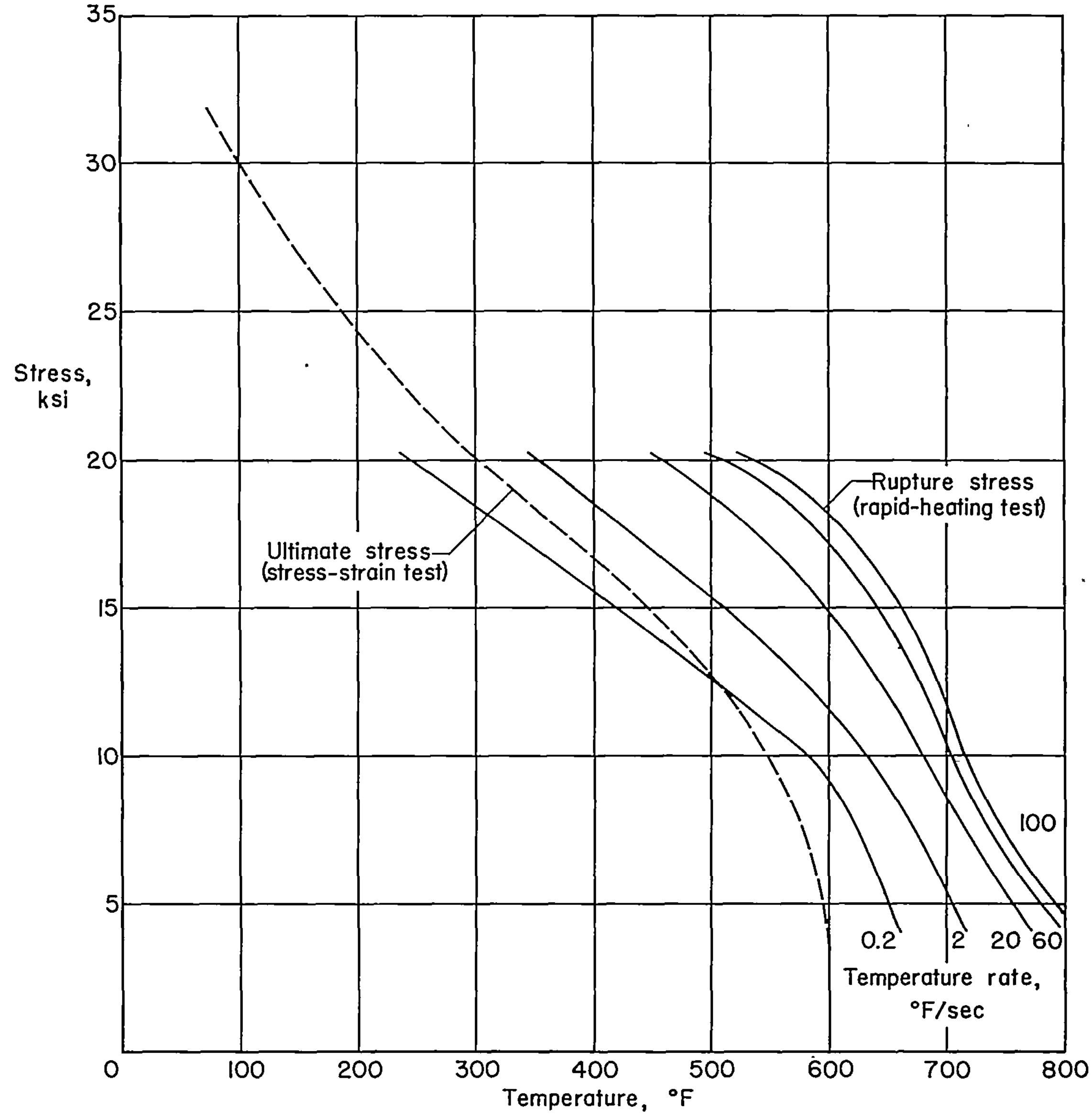

Figure 9.- Tensile rupture stress of HK31XA-H24 magnesium-alloy sheet for rapid-heating tests from 0.2° F to 100° F per second and tensile ultimate stress for stress-strain tests after $\frac{1}{2}$-hour exposure.

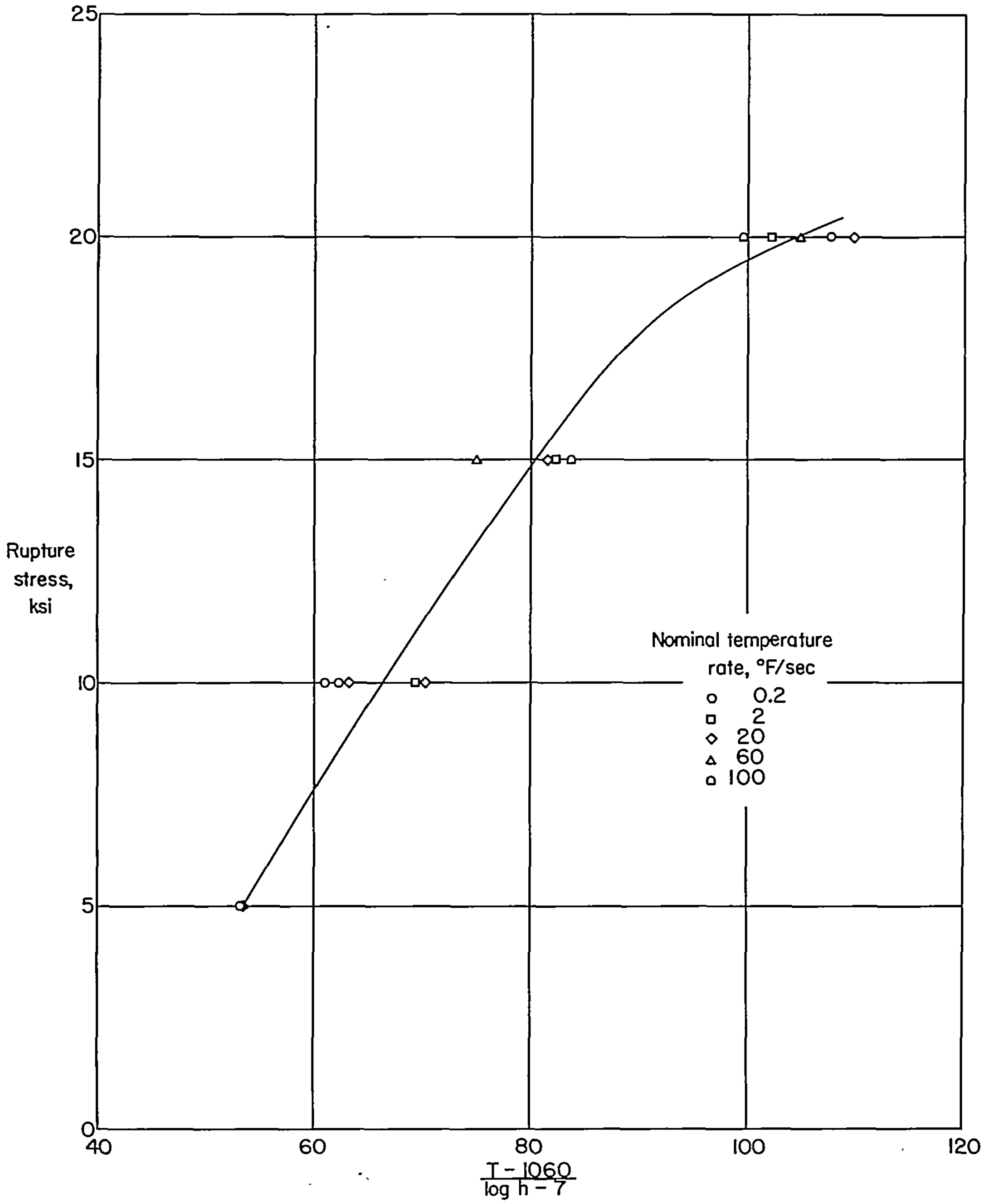

Figure 10.- Master curve for rupture temperatures and stresses of HK31XA-H24 magnesium alloy, using the temperature-rate parameter $\frac{T - 1060}{\log h - 7}$ (T is in $^{\circ}$F and h is in $^{\circ}$F per second).

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